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Crossing the bridge to elementary school: The development of children's working memory components in relation to teacher-student relationships and academic achievement

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Abstract

Working memory is important for a variety of life domains, including for children's school functioning. As such, it is crucial to understand its development, antecedents and consequences. The current study investigates the development of different working memory components (phonological loop, visuospatial sketchpad, central executive), the influence of different aspects of the teacher-student relationship (closeness, conflict, dependency) and its predictive value for academic achievement (reading, spelling, mathematics) across the transition from kindergarten to first grade. The sample consisted of 107 kindergarten children. Working memory tasks were administered at the end of kindergarten and first grade. Teachers reported on teacher-student relationship quality in the middle of first grade. Standardized tests were used to assess academic achievement at the end of first grade. Results indicate moderate to large increases in the phonological loop and visuospatial sketchpad and large gains in the central executive. Dependency of the student towards the teacher significantly predicted visuospatial sketchpad performance at the end of first grade. Reading was significantly predicted by the visuospatial sketchpad and phonological loop in kindergarten, while for spelling the visuospatial sketchpad was important. Finally, mathematics was predicted by performance on the phonological loop and the visuospatial sketchpad. The current study indicates the importance of the affective quality of the teacher-student relationship for working memory performance, which in turn is important for academic achievement. It is therefore critical to attend to the early detection and prevention or intervention of working memory problems in the classroom in order to prevent future academic problems. Additionally, maintaining a positive relationship with students and encouraging their independent exploration may be important when preventing such problems, complementary to cognitive or other types of training and intervention.

Keywords: Working memory, Teacher-student relationship, Academic Achievement, First grade, Transition

Introduction

For children's school functioning, working memory is of utmost importance. Children use their working memory throughout the day in the classroom, both in showing positive behavior (e.g., positive work habits and engagement in learning; Brock, Rimm-Kaufman, Nathanson & Grimm, 2009) and during academic tasks (e.g., Alloway & Alloway, 2010). Because of the importance of working memory for outcomes in the classroom, understanding its development, antecedents and consequences can help to prevent a wide range of educational problems. Recent research shows that factors in the classroom environment, such as the teacher-student relationship, influence the performance on working memory tasks (e.g., de Wilde, Koot & van Lier, 2015).

However, empirical research examining the role of the teacher-student relationship in working memory and the role of working memory for academic achievement is scarce. Moreover, previous studies do not always distinguish between the different working memory components, limiting our insights into their relationships with different aspects of the teacher-student relationship and academic achievement. Therefore, the current study aims to investigate these relationships during children's transition from kindergarten to first grade, an important period in the development of working memory.

Executive Functions and Working Memory

Executive functions are cognitive processes that are essential in making goal-directed behavior possible (Diamond, 2013; Zelazo & Carlson, 2012). There are three core executive functions: working memory, inhibition and cognitive flexibility. Working memory is an executive function that starts to develop early in life and is important for various outcomes across the lifespan (e.g., mental and physical health; Diamond, 2013). This memory system is responsible for holding information in mind, including new information (updating) and mentally manipulating this information. We use working memory, for example, to calculate, to find out the meaning of written information, to execute complex instructions or to combine multiple sources of information before making a decision.

Working memory development in school

Baddeley (1986) conceptualized working memory as a multicomponent system. His model distinguishes two slave systems, the phonological loop and the visuospatial sketchpad. The phonological loop can temporarily store verbal information and rehearse this information or update it with new information in order to support recall of the information (Baddeley, 1986; Gathercole, Pickering, Ambridge & Wearing, 2004). The visuospatial sketchpad can temporarily hold information with a visual or spatial nature (Baddeley, 1986; Gathercole et al., 2004). Both these components are controlled by the a third aspect of working memory, the central executive. In this component information is not merely stored, both actively processed and manipulated (Baddeley, 1986; Gathercole et al., 2004). This system is used, for example, when making a calculation: the numbers and operators need to be remembered and the information needs to be manipulated when making the calculation. Later, Baddeley added a fourth component, the episodic buffer, that integrates information of different memory systems into episodic representations (Baddeley, 2000). However, due to the lack of reliable measures for this component in young children, the current study will make use of the three component model (de Pontes Nobre et al., 2013).

In very young children (age 4) the central executive and phonological loop have been found to be distinguishable (Alloway, Gathercole, Willis & Adams, 2004). From the age of 6 the three factor model provides the best fit (Gathercole et al., 2004). At this age the phonological loop and visuospatial sketchpad show a relatively strong relationship with the central executive (r = .73-.85; Gathercole et al., 2004).

The development of working memory depends (in part) on the maturation of the prefrontal cortex (Anderson, 2002). Working memory abilities start to develop early in life (Diamond, 2013; Reznick, Morrow, Goldman & Snyder, 2004), show important developmental spurts during preschool and the early years of formal schooling (ages 3-8; Ganea & Harris, 2013; Hongwanishkul, Happaney, Lee & Zelazo, 2005; Kibbe & Leslie, 2013; Moher & Feigenson, 2013) and continue to develop gradually at least until adolescence (Conklin, Luciana, Hooper & Yarger, 2007; Gathercole et al., 2004). Different components of working memory show different developmental trajectories. For example, the central executive starts to develop later than the two slave systems (Davidson, Amso, Anderson & Diamond, 2006; Garon, Bryson & Smith, 2008), suggesting it is likely to show rapid improvements around the time of transition to first grade. In first grade, the classroom environment becomes more complex and greater demands are placed on children's working memory (e.g., more complex instructions; Cuevas, Hubble & Bell, 2012; Hughes, Ensor, Wilson & Graham, 2010; Roebers, Röthlisberger, Cimeli & Michel, 2011). Such changes can influence the development of working memory, for example by challenging children's working memory abilities, giving this development an additional boost (Roebers et al., 2011). Despite the importance of this transition, the number of studies examining working memory development specifically at this point in time are limited.

Working Memory and the Teacher-Student Relationship

Although the development of working memory is largely driven by the maturation of the prefrontal cortex, this maturation occurs in interaction with environmental stimulation in periods of rapid development (Huttenlocher, 2002). When children enter formal schooling, the classroom context becomes an important part of children's environment in which stimulation can be provided. A high-quality teacher-student relationship, characterized by high closeness, low conflict and low dependency, has previously been shown to have a positive effect on several aspects of children's development, including social development, cognitive functioning and academic performance (Downer, Sabol & Hamre, 2010; Verschueren & Koomen, 2012).

The attachment perspective, often employed in teacher-child relationship research, can explain how aspects of the teacher-student relationship can affect working memory (Roorda, Koomen, Spilt & Oort, 2011; Verschueren & Koomen, 2012). According to this view, children who have a positive affective relationship with their teacher (e.g., high closeness, low conflict, low dependency) use the teacher as a secure base from which to explore the school environment (Roorda et al., 2011). As such, children with a positive teacher-child relationship will engage more in stimulating learning activities, which is likely to promote the development of the prefrontal cortex and aspects of working memory. Additionally, children who view the teacher as a safe haven will return to the teacher when distressed, leading to more optimal stress regulation (Roorda et al., 2011). A study of Ahnert, Harwardt-Heinecke, Kappler, Eckstein-Madry and Milatz (2012) indeed shows that children sharing a positive relationship with their teacher show more optimal patterns of stress regulation. In turn, stress has been found to negatively affect the development and functioning of the prefrontal cortex, executive functioning and working memory (Diamond, 2013; Hughes, 2011; Kolb et al., 2012). The three different components of working memory can each be influenced by a positive teacher-child relationship. Rapidly developing components, such as the central executive around the transition to first grade, are more likely to be influenced, as their underlying brain regions undergo large changes and are most sensitive to environmental stimulation (Huttenlocher, 2002).

A recent study of de Wilde and colleagues (2015) found a bidirectional relationship between child-perceived teacher-child relationship quality and children's performance on a task measuring the central executive at the age of 5 to 8. Cross-lagged models show that especially conflict in the relationship seemed detrimental, while warmth between the teacher and the student had a modest positive effect. Similarly, Hamre, Hatfield, Pianta and Jamil (2014) found a positive relationship between observed sensitive teaching and classroom organization with the central executive component of working memory at the age of 4. Both a positive classroom climate and positive affective relationships between the teacher and specific students can thus promote working memory. Hence, the first results of studies examining the relationship between teacher-student interactions and working memory are assuring, though studies are still scarce and focus mainly on the central executive. It is therefore unclear how the teacher-student relationship relates to the different subcomponents of working memory.

Working Memory and School Functioning

Working memory development in school

Understanding the development of working memory is important as good working memory abilities relate to positive outcomes in a number of domains, such as children's school functioning (Diamond, 2013). Previous research has shown a positive relationship between working memory abilities and academic achievement in school aged children after controlling for children's fluid and crystallized intelligence (e.g., Alloway & Alloway, 2010; Desoete & De Weerdt, 2013; De Weerdt, Desoete & Roeyers, 2013). However, results are not always consistent, with some studies showing no or limited relationships between working memory and mathematics (Bull & Lee, 2014; Friso-van den Bos, van der Ven, Kroesbergen & van Luit, 2013) or reading (Lan, Legare, Ponitz, Li & Morrison, 2011).

Recent research indicates that different components of working memory may be differentially related to specific aspects of academic achievement, namely mathematics, reading and spelling, though results are sometimes inconsistent. The study of Meyer, Salimpoor, Wu, Geary and Menon (2010), for example, showed that accuracy of numerical operations was related with the visuospatial sketchpad only, while working out mathematical word solving problems was associated with all working memory components. Also, De Smedt and colleagues (2009) showed an important contribution of the central executive and the visuospatial sketchpad in first grade mathematics achievement, while second grade mathematics achievement was predicted by the central executive and the phonological loop, suggesting different components of working memory might be important in different stages of mathematics development. In the case of word reading, the phonological loop and central executive are important, but not the visuospatial sketchpad (Zheng, Swanson & Marcoulides, 2011), while spelling is associated to the visuospatial sketchpad (Brandenburg et al., 2015). Most studies provide information about associations between working memory and academic achievement. However, information about the predictive value of working memory components, especially at the beginning of formal education, can be useful for the purpose of prevention of academic difficulties.

The Current Study

In sum, evidence is accumulating that the teacher-student relationship is important for children's working memory performance, which in turn relates to children's academic achievement. Yet, it is unclear whether the teacher-student relationship has predictive value for working memory development and to what extent working memory performance in kindergarten is predictive of academic achievement in first grade. This limits our insights and impedes the efficient prevention of working memory problems and associated problems in school functioning.

The current study therefore investigates three research questions. First, how do different working memory components develop when children make the transition to elementary school? It is expected that different components of working memory develop at different rates during this transition, with especially the central executive showing rapid growth (Davidson at al., 2006; Garon et al., 2008). Second, how do different dimensions of the teacher-student relationship (closeness, conflict, dependency) relate to different components of working memory (phonological loop, visuospatial sketchpad, central executive) at the end of first grade? Based on previous research it is expected that especially closeness and conflict in the teacher-student relationship will (positively and negatively) affect working memory (de Wilde et al., 2015). Although the mechanisms underlying such relationships are likely to influence all components of working memory, the central executive – which develops very rapidly at the time of transition to first grade - is most likely to be receptive to environmental influences (Davidson et al., 2006; Huttenlocher, 2002). Third, which components of working memory in kindergarten and first grade predict which aspects of academic achievement (reading, spelling, mathematics) at the end of first grade? The central executive is anticipated to be associated with all three academic skills, while the phonological loop is most likely related to reading and spelling and the visuospatial sketchpad to mathematics (De Smedt et al., 2009; Meyer et al, 2010; Zheng et al., 2011).

Methods

Participants

Children, their parents, and their teachers were recruited through regular kindergarten schools (no schools with special education were included) in XXX. Twenty schools (33 classrooms) participated in the study. Parents of 107 children (M_{age}=5.88, SD_{age}=0.29) provided written informed consent in kindergarten. Of this sample, parents of 89 children (83.2%, M_{age}=6.88, SD_{age}=0.28) participated in the follow-up measure at the end of first grade. In the middle of first grade, teachers were asked to fill in a questionnaire on the teacher-student relationship. In 16 classrooms teachers agreed to provide this information, resulting in a subsample of 51 participants (M_{age1}=5.97, SD_{age1}=0.26, M_{age2}=6.95, SD_{age2} = 0.26).

Table 1 shows background information of the children in the current sample. There were approximately equal numbers of boys and girls. The majority of the children were monolingual XXX speaking, lived in a two-parent-biological family, had a mother with at least a Professional Bachelor's degree and had an income above the poverty line. When comparing the follow-up group to the group that dropped out of the study differences were found indicating that especially children from one-parent or reconstituted families, children with a low-educated mother and children from families with an income below the poverty line did not participate in the follow-up measurement at the end of first grade. Similar differences were found between children whose teacher did and did not participate in the measurement of the teacher-student relationship quality in the middle of first grade.

Measures

Background characteristics.

Children's gender and age were reported by the parents. Parents provided information on the language spoken at home (monolingual XXX speaking or bilingual), the family structure (two-parent-biological family, single-parent or reconstituted family), their level of education (secondary education or less, at least a Professional Bachelor's degree) and family net monthly income. Based on the family net income, families income was classified as below or above the at-risk-of-poverty-line, which in XXX is set at 60% of the national median income after social transfers (Dierckx, Van Herck & Vranken, 2010).

Parents also reported on their age at the birth of their first child. Finally, mothers indicated whether or not they had smoked (at least once) during pregnancy.

As children's demographic background has previously been shown to relate to both working memory (e.g., Calvo & Bialystok, 2014) and academic achievement (e.g., Sirin, 2005) background characteristics were added in the analysis as control variables. Because a combination of demographic risk factors, rather than individual aspects of children's demographic background are important (e.g., Cadima, William & Leal, 2010; Rhoades, Greemberg, Lanza & Blair, 2011) a cumulative risk factor was calculated. First, family structure, mothers' educational level, risk-of-poverty, mothers' age at first birth and smoking during pregnancy were recoded into dichotomous variables. Single-parent and reconstituted families, mothers with a degree in secondary education or lower, families below the poverty-line, mothers below 25 years of age (below 25th percentile) and mothers who smoked during pregnancy were coded as one on the respective variable, reflecting the presence of a risk factor. Then, the sum of these five variables was calculated to provide a score indicating the number of risk factors characterizing each participant (ranging from 0 to 5).

Working memory.

To measure working memory the XXX version of the Automated Working Memory Assessment (AWMA; Alloway, 2007) was used. Eight out of twelve subtests were selected, measuring the phonological loop, visuospatial sketchpad and (verbal and visual) central executive. Two subtests (i.e., Counting Recall and Mazes Memory) were not administered because a pilot test showed the instructions of these tests to be very difficult for children at the end of kindergarten. Two more subtests (i.e., Non-word Recall and Spatial Recall) were left out in order to have an equal number of subtests for each working memory component. Non-word Recall and Spatial Recall had the lowest test-retest reliability (Alloway, 2007). Test-retest reliability of the selected subtests ranged between .84 and .90 (Alloway, 2007).

The AWMA test battery is administered by means of a computer. In each subtest children had to remember something. The child receives verbal instructions and practice trials before each subtest. Difficulty was increased when the child performed well (i.e., four correct trials of the same difficulty) and the subtest was ended when it became too difficult (i.e., three incorrect trials of the same difficulty). For each subtest, a score was calculated based on the number of correct trials. A higher score indicated better performance.

Phonological loop. The phonological loop was measured with the subtests Digit Recall and Word Recall, in which children had to remember and repeat a sequence of digits or words, respectively.

Visuospatial sketchpad. Dot Matrix and Block Recall assessed the capacity of the visuospatial sketchpad. In Dot Matrix a sequence of dots lighted up in a 4x4 matrix. After the sequence the child indicated the spacing of the dots in the correct order. Block Matrix is a computerized version of the Corsi Block Taping Test. It consisted of remembering and repeating the spacing of a sequence of blocks, which were indicated on a board with nine irregularly spaced blocks.

Central executive. The central executive was assessed with two verbal subtests, Listening Recall and Backwards Digit Recall, and two visual subtests, Mister X and Odd One Out. During these four subtests the child had to process or manipulate information in addition to remembering information. In Listening Recall the child had to judge whether a sentence is true or false. After a series of sentences the child repeated the first word of all the sentences in the correct order. In Backwards Digit Recall the child had to repeat a sequence of digits in reverse order. In Mister X the child first decided whether two figures held a ball in the same or the opposite hand. After a series of figures the child had to recall where the ball was located each time. In Odd One Out the child saw a row of three abstract figures. The child first decided which figure was different from the other two. After a series of rows the child had to recall the location of each ‘odd’ figure.

Teacher-student relationship quality.

Teachers completed the XXX version of the Student-Teacher Relationship Scale (Koomen, Verschueren, Van schooten, Jak & Pianta, 2012; Pianta, 2001) to evaluate closeness, conflict and dependency in the relationship between the teacher and the child. Teachers judged statements about their relationship with the child on a 5-point scale (1 = not applicable, 5 = applicable). Closeness is measured with 11 items (e.g., ‘I share an affectionate, warm relationship with this child’). By summing the scores of individual items a score for closeness is calculated, with a minimum of 11 and a maximum of 55. Conflict is also assessed with 11 items (e.g., ‘This child easily becomes angry with me’), resulting in a score between 11 and 55. The Dependency-scale consists of 6 items (e.g., ‘This child reacts strongly to separation from me’) and has a score between 6 and 30. A higher score on closeness indicates a better relationship between the child and the teacher. Higher scores on the scales of conflict and dependency imply a more negative relationship between the child and the teacher.

The XXX version of the Teacher Student Relationship Questionnaire is a reliable instrument, with Cronbach’s alphas of .88, .90 and .78 for the scales Closeness, Conflict and Dependency (Koomen et al., 2012). Evidence for factorial validity (e.g., Koomen et al., 2012) and for convergence with observed teacher-child relationship quality (e.g., Doumen, Koomen, Buyse, Wouters, & Verschueren, 2012) has also been provided. In the current study the items 21, 25 and 6, of the Closeness, Conflict and Dependency scale respectively, were deleted as these item scores showed no correlation with their respective scale scores and lowered the internal consistency of the scales. After this deletion, Cronbach’s alphas were .85, .89 and .82 for the scales Closeness, Conflict and Dependency respectively.

Academic achievement.

Children’s reading, spelling and mathematics achievement were assessed with standardized achievement tests that are commonly used in XXX.

For reading the Three-Minutes-Test for XXX (Moelands, Kamphuis & Rymenans, 2003) was administered. In this test three word lists of increasing difficulty were presented to the child. The child was instructed to read the word list as fast and accurately as possible for one minute. The number of accurately read words was recorded for each list. The third list of words was rather difficult for children of this age, resulting in a floor effect (with more than 30% of children not being able to read 10 words in a minute). The score on this list was therefore not used in further analyses. Previous research has found high reliability scores for this test (.90; Vanbist, Ansari, Ghesquière & De Smedt, 2016).

The spelling test (Moelands & Rymenans, 2003) consisted of 41 items. For each item a sentence was read to the child, followed by the repetition of a single word which was then written down by the child. The number of correct words was summed to receive a total score for the test. Previous studies have shown high internal consistency of the spelling test (α=.92; Verachtert, Ghesquière, Hendrikx, Maes, & Van Damme, 2005), which was confirmed in the current study (α=.89).

Mathematics was assessed with a standardized achievement test (Dudal, 2006) of 40 items, evaluating number sense (10 items), arithmetic word problems (10 items), estimation (5 items), number decomposition (10 items) and number series (5 items). Each item was read out loud twice by the researcher. The items of the estimation scale and one item of the word problems scale (item 13) were deleted as they showed a very low correlation with the rest of the test. This test has been shown to have good internal consistency (α = .92; Verachtert et al., 2005). In the current study similar reliability was found (α = .91).

Procedure

At the end of kindergarten (March-June) children's working memory performance was tested. At the end of first grade (March-June) working memory was measured again and the academic achievement tests were administered. Between both working memory assessments there were 357 days on average (SD = 18 days). Children were tested individually in a quiet room at school or at their homes for approximately 45 minutes each time. All tests were administered in the same order. At the end of the final testing in kindergarten and first grade, children received an age-appropriate gift as an appreciation for their participation. During the first term of first grade (December-January) teachers completed the questionnaire about the teacher-student relationship quality.

Analyses

Preliminary analyses were conducted in IBM SPSS Statistics 23.0 (IBM Corp., 2013) to examine the average change in performance on the different working memory tasks across the transition to first grade. To this end repeated measures ANOVA were conducted and Cohen's d were calculated for each of the working memory tasks.

In order to examine (1) the predictive role of the teacher-student relationship for the working memory subcomponents and (2) the predictive role of kindergarten working memory for children's academic achievement in first grade, Structural Equation Modeling was performed in Amos SPSS (Arbuckle, 2014). First, Confirmatory Factor Analysis was used to evaluate the working memory model as outlined in the introduction and method section. Second, the structural model was evaluated by examining the path coefficients. The current analyses started with a full model (Figure 1). In the full model, pathways were included from kindergarten working memory to first grade working memory, from the aspects of the teacher-child relationship to working memory in first grade and from working memory in kindergarten to academic achievement. Additionally, pathways were added from the cumulative risk-variable to all other variables and directly from the teacher-child relationship aspects to academic achievement, as previous research has shown such relationships might also be present (Calvo & Bialystok, 2014; Downer, Sabol & Hamre, 2010; Sirin, 2005; Verschueren & Koomen, 2012). Non-significant pathways were deleted one by one until only significant pathways remained. A separate model was run for reading, spelling, and mathematics and for closeness, conflict and dependency, resulting in nine different models. Conclusions from these models were the same as conclusions drawn from models including all dimensions of the teacher-child relationship simultaneously.

For 51 children, data were available on the quality of the teacher-student interaction. For 89 children working memory data were available for both kindergarten and first grade. Full Information Maximum Likelihood was used to handle missing data. This approach allows all information available to be incorporated in the analyses and is seen as a state of the art approach (Baraldi & Enders, 2010). There were three outliers identified in the subscales conflict (2 outliers) and dependency (1 outlier). However, as these are likely to truly reflect the presence of negative interactions in the teacher-student relationship, these three children were included in the analysis. No outliers were identified in any of the working memory tasks.

Results

Working Memory Development

Table 2 shows the descriptive statistics of the working memory tasks in kindergarten and first grade and the repeated measures test examining the change in children's performance on each task from kindergarten to first grade. Cohen's d is calculated and differences are interpreted as small above .20, medium above .50 and large above .80 (Cohen, 1992).

Children's performance on all working memory tasks increased significantly from kindergarten to first grade. The two measures of the phonological loop, Digit Recall and Word Recall, showed large and moderate increases in performance, respectively. Both Dot Matrix and Block Recall, indicators of the visuospatial sketchpad, demonstrated moderate growth. For both measures assessing the central executive processing verbal information, Listening Recall and Backwards Digit Recall, a large increase could be observed. Similarly, the central executive processing visuospatial information, Odd One Out and Mister X, showed a large increase in performance.

Structural Equation Modelling

Working memory model.

Confirmatory Factor Analysis was used to examine the appropriateness of the working memory model introduced earlier and to assure that the same model could be used both in kindergarten and first grade. Based on the chi-square statistic, the original model did not provide a food fit for the current data. Both in kindergarten and in first grade, the score of 'Mister X' had a low loading on the factor 'central executive'. This task was therefore deleted in both models, resulting in a model that provided an acceptable fit, both in kindergarten ($\chi^2(11) = 18.67$, $p = .067$) and in first grade ($\chi^2(11) = 15.56$, $p = .158$). It was examined whether the models at both time points were the same (Table 3). First, a model was estimated allowing factor loadings to freely vary across the two time points. Although chi-square was just below significance level, the Comparative Fit Index (CFI) was good and the Root Mean Square Error of Approximation (RMSEA) was adequate. This indicates configural invariance, the structure of working memory is the same across both time points. Additionally, a constrained model, with equal factor loadings and variances at both time points, was estimated. Results were the same and the difference between the two models was non-significant. This indicates metric invariance across both time points. Factor loadings of the final models are reported in Table 4.

Teacher-child interactions and working memory performance.

The correlations between the working memory tasks and dimensions of the teacher-child relationship can be found in Table 5.

The final models show that closeness and conflict in the middle of first grade were not related to any of the working memory subcomponents at the end of first grade. Dependency in the middle of first grade significantly predicted performance on the visuospatial sketchpad at the end of first grade ($\beta = -.43$, $p = .018$). Higher levels of dependency in the teacher-child relationship predicted lower performance on tasks measuring the visuospatial sketchpad. The relationship between dependency and the phonological loop and central executive were non-significant.

Working memory performance and academic achievement.

The correlations between the working memory tasks and aspects of academic achievement can be found in Table 5.

With regard to the prediction of academic achievement at the end of first grade based on working memory performance in kindergarten, several significant pathways were found. With regard to reading, both the phonological loop ($\beta = .29$, $p = .004$) and the visuospatial sketchpad ($\beta = .30$, $p =$

.019) were significant predictors. While controlling for cumulative risk, working memory predicted 18% of the variance in reading performance. Spelling was only significantly predicted by the visuospatial sketchpad ($\beta = .71$, $p < .001$) and not the phonological loop or the central executive. This model explained 52% of the variance in the spelling scores. Finally, mathematics was also predicted by both the phonological loop ($\beta = .37$, $p < .001$) and the visuospatial sketchpad ($\beta = .48$, $p < .001$), with a total of 37% of the variance in mathematics explained. In all of these cases, higher working memory scores predicted higher academic achievement. The central executive did not significantly predict any of the aspects of academic achievement.

Discussion

The current study aimed to investigate how different components of working memory (i.e., phonological loop, visuospatial sketchpad, central executive) developed during the transition from kindergarten to first grade, how the teacher-child relationship quality in the middle of first grade relates to working memory at the end of first grade, and how working memory performance in kindergarten predicts academic achievement at the end of first grade.

Development of Working Memory

First, the development of working memory subcomponents was examined. All components of working memory showed improvements between kindergarten and first grade in the current study. Children’s performance on the tasks assessing the central executive both processing verbal and visuospatial information demonstrated large increases. Tasks measuring the phonological loop showed moderate to large growth, while the visuospatial sketchpad showed moderate growth.

Previous research has shown that the slave systems of working memory start to develop very early in life, go through a rapid development before primary school and continue to develop more gradually from primary school to at least adolescence (Gathercole et al., 2004; Hongwanishkul et al., 2005; Conklin et al., 2007). The central executive, however, starts to develop later, around the age of three, and shows remarkable improvements before and during the early years of primary school (Diamond, 2013; Davidson et al., 2006; Garon et al., 2008). The current results, indicating a moderate development of the slave systems compared to large increases in the central executive during the transition to first grade, support these previous findings. Only the Digit Recall task, which assessed the phonological loop, showed a large improvement over the transition to first grade. It is possible that when children start formal mathematics education in first grade, they become more familiarized with numbers, making it easier to remember sequences of numbers, as is required in the Digit Recall task.

Teacher-Student Relationship and Working Memory

Second, the predictive nature of different dimensions of the teacher-student relationship (i.e., closeness, conflict, dependency) for performance on different working memory components at the end of first grade was examined. Results indicate that high levels of dependency in the teacher-student relationship negatively influence the visuospatial sketchpad at the end of first grade.

Due to the prolonged development of the prefrontal cortex, on which working memory relies, maturation and environmental factors both play a role in working memory development (Hughes, 2011; Kolb et al., 2012). Environmental influences can be negative (e.g., stress), as well as positive (e.g., parental sensitivity), and as such slow down or stimulate working memory development (Hughes, 2011). Especially during periods of rapid growth, which can be seen for the working memory components in this study, environmental factors can have a pronounced influence on brain structures and related cognitive processes (Anderson, 2002).

The current study showed a direct influence of dependency in the teacher-student relationship on working memory, more specifically on the visuospatial sketchpad. Children showing high levels of dependency in the teacher student relationship are often clingy towards the teacher and request help continuously, even for tasks or activities for which the help of the teacher is not needed (Verschueren & Koomen, 2012). Thus, they tend to rely less on the teacher as a secure base and explore the environment less, which likely leads to less opportunities to practice and develop working memory abilities. Moreover, children showing high levels of dependency tend to have higher stress levels and poorer stress regulation (Ahnert et al., 2012), which additionally creates an adverse environment for working memory development. The results of the current study suggest that teachers can promote children's cognitive functioning by stimulating them to work independently, explore the classroom environment and persist when faced with difficult tasks. The current study also calls for more research on the role of teacher-child dependency for children's development in school, as this is the dimension that has been studied least in the teacher-child relationship literature, and hence, remains less well understood (Doumen, Verschueren, Buyse, De Munter, Max & Moens, 2009).

Contradictory to the expectations, teacher-student relationship quality only related to performance on the visuospatial sketchpad and not to the other components of working memory. Previous research has shown the central executive to be influenced by the teacher-student relationship (de Wilde et al., 2015; Hamre et al., 2014). However, several studies investigating the effects of working memory training have found the visuospatial sketchpad to be more improved or show more pronounced near transfer to untrained tasks after training (e.g., Holmes, Gathercole & Dunning, 2009; Phillips et al., 2016). It thus seems that the visuospatial sketchpad can be more influenced by stimulation. The reason for this is unclear. It is possible that verbal and visuospatial aspects of working memory relate to different processes, for example phonological and attentional processes (Dahlin, 2011), and these may be influenced by different types of environmental influences. Alternatively, if low levels of dependency promote working memory performance through increased levels of children's exploration, the type of working memory processes that are stimulated would depend on the type of challenging activities the child encounters in the classrooms. If these are more visually in nature, this may affect the visuospatial sketchpad more and the current result would thus be classroom dependent. Finally, it should be noted that other environmental factors (e.g., classroom organization, parent-child relationship quality; Hamre et al., 2014; Hughes, 2011) may have influenced working memory performance and thus confound the results. More research is needed to entangle the influence of the teacher-student relationship on specific subcomponents of working memory and the mechanisms underlying these relationships.

Unexpectedly, closeness and conflict were not related to any of the working subcomponents. Closeness is a positive aspect of the teacher-student relationship and has, in general, been linked to positive child outcomes, while conflict in general has a negative impact on child development (Roorda et al., 2011). The study of Ahnert and colleagues (2012), however, suggests that perhaps it is the combination of dimensions in the teacher-student relationship (e.g., high levels of closeness combined with medium or low levels of conflict and dependency) that are important for children's functioning rather than the dimensions as such. Additionally, it should be noted that the small sample size and limited variability in the conflict dimension may have restricted the opportunities of exposing additional effects of the teacher-student relationship on the different working memory components.

Working Memory and Academic Achievement

Finally, our study also aimed to investigate the predictive nature of working memory performance in kindergarten for academic achievement in first grade.

In this study, children with a higher performance on the phonological loop and the visuospatial sketchpad at the end of kindergarten could read more words correctly within the given time, at the end of first grade. These results are only partially in line with previous research, which suggests a particular importance of the phonological loop and central executive in children's word reading (e.g., Zheng et al., 2011). Similarly, studies on dyslexia emphasize the importance of phonological processes and the phonological loop in reading difficulties (e.g., Dandache, Wouters & Ghesquiere, 2014). Other studies however, emphasize the importance of both phonological and visual processes in reading and indicate that the relationship between the components of working memory and reading abilities depend on the reading strategy used. In general, it is assumed that words can either be read through a direct route, involving immediate word recognition (and visuospatial processes), and an indirect route, involving the decoding of each grapheme into a phoneme (involving both phonological and visuospatial processes; e.g., Jobard, Crivello & Tzourio-Mazoyer, 2003). The current study seems to suggest that children use both of these, and are likely to tap into the visuospatial sketchpad for the direct reading of easy words, while they likely make more use of the phonological loop for difficult words, which have to be decoded. Some studies indeed show independent contributions of both phonological and visuospatial processes in early reading (Deacon, 2012; Gathercole, Alloway, Willis & Adams, 2006).

The visuospatial sketchpad played a central role in the performance on the spelling test. This is in line with previous research indicating that the visuospatial sketchpad, but not the phonological loop and central executive are related to spelling (Brandenburg et al., 2015). The current study suggest not only an association, but indicates a predictive relevance of early performance on the visuospatial sketchpad for early spelling processes.

Though it was expected that the visuospatial sketchpad rather than the phonological loop would be important for mathematics achievement, both were found to have an influence. This is partially in line with the study of De Smedt and colleagues (2009) showing that the visuospatial sketchpad is particularly important for mathematics at an early stage (first grade), while the phonological loop is involved in mathematics at a later stage (second grade). In the current study, both were important for first grade mathematics achievement. It is possible that the nature of the mathematics test used in the current study has influenced the results, as this test contained mostly items which are verbally formulated rather than symbolic mathematics exercises and thus may require well-developed verbal memory.

The lack of predictive value of the central executive for academic achievement was surprising, since previous studies have found such relationships (e.g., De Smedt et al., 2009; Zheng et al., 2011). These studies generally looked at children from school-age onwards. It is possible that in kindergarten children, the working memory tasks are still very difficult for the majority of the children and therefore lack sensitivity in predicting other variables. It is also possible that the use of specific working memory components differs in different age groups, as also noted in the introduction (e.g., De Smedt et al., 2009). This is in line with a study of Bull, Espy and Wiebe (2008) where measures of the central executive became more important around the age of 7-8, while the visuospatial sketchpad was on the forefront in the prediction of mathematics achievement around the age of 6. Related to this, subcomponents of working memory may be differently related to specific tasks of academic achievement (Bull et al., 2008). For example, simple tasks of mathematics and reading (e.g., mental calculation or simple word problems) may be guided by simpler processes (e.g., fact retrieval) compared to more complex tasks (e.g., complex word problems). More complex exercises, which are more often present in academic achievement tests for older children, may require the use of the central executive more.

Strengths and Limitations

Previous research examining the relationships between teacher-student relationship quality, working memory and school functioning often use general measures for one or more of these concepts, without distinguishing different components. As a consequence, more nuanced insights into how the different aspects of each construct relate to each other was still lacking. The current study was a first attempt to improve our understanding by thoroughly measuring working memory at the subcomponent level and assessing different dimension of both the teacher-student relationship and academic achievement. Additionally, the current study used a longitudinal design. Accordingly, this study was able to build our understanding of the predictive nature of the different concepts in relation to each other, instead of merely describing relationships.

Despite the fact that the current study has broadened our understanding of working memory development within a school context, results of the current study should be interpreted in light of some limitations. First, the sample size used in the current study was rather small. Although the model should be able to detect medium effects, it should be noted that relatively small effects might not have been detected. It was also not possible to use multilevel analyses, although preliminary analyses suggest that due to insufficient between-classroom variability the use of multilevel analyses would not be necessary in the current sample. Further research should explore the links between the teacher-child relationship, children's working memory and academic achievement in larger samples. Additionally, the current sample comprised typically developing children, mainly from advantaged families. Children from low SES families, children with behavioral problems or children with a psychiatric disorder may be at risk for problems with regard to working memory or the teacher-child relationship and the importance of these processes for their functioning in the classroom might be even more important (e.g., Buyse, Verschueren, Doumen, Van Damme & Maes, 2008; Calvo & Bialystok, 2014). Future studies should examine whether the studied processes are similar in these types of samples. Second, it should be noted that, although the one-year longitudinal design of the current study provides important information, a more elaborate longitudinal design spanning several years and including multiple time-points of the different measurements could further broaden our insights. This is especially the case for the teacher-student relationship, which has been shown to be a dynamic rather than a static environmental factor that can have bidirectional links to child characteristics such as working memory (de Wilde et al., 2015; Spilt, Hughes, Wu & Kwok, 2012). Moreover, the current study design does not allow to draw any conclusions about causal relationships. Future studies should consider a broader range of control variables or include other designs such as an intervention study. Third, the measurement of the teacher-student relationship was limited to the perceptions of the teacher and did not include information on the broader relationships within the classroom environment. Recent studies have shown that aspects of the broader classroom environment, such as the general classroom climate, can also impact children's functioning or moderate the effects of the teacher-student relationship on working memory (Buyse, Verschueren, Verachtert & Van Damme, 2009). Moreover, agreement between teacher and student perspective on the quality of their relationship has been shown to be low to modest (Spilt, Koomen & Mantzicopoulos, 2010). The perspective of the child might be more predictive of the development of a child characteristic like working memory. Finally, the results of the current study suggest differential relationships between different aspects of the teacher-student relationship, components of working memory and different aspects of academic achievement and child behavior. However, the current study can draw no conclusions on the underlying mechanisms of these relationships. Further research is necessary to explore these mechanisms.

Conclusion and Implications

The current study investigated the relationships between aspects of the teacher-student relationship, components of working memory and aspects of children's academic achievement when they make the transition to first grade. First, results show that working memory components still show remarkable growth when children make the transition to formal schooling. As classroom activities often place higher demands on children's working memory after this transition (Hughes et al., 2010), it should be taken into account that children might not always be able to meet those demands.

Second, the current study shows that components of working memory are influenced by the quality of the teacher-student relationship, more specifically, by the levels on dependency within this relationship. When difficulties in specific components of working memory arise, focusing on improving specific aspects of the relationship between teacher and student might promote working memory development at least to some degree. The findings suggest that especially the secure base function of teachers may be important in this respect and that teachers should attempt to increase the child's comfort in the classroom and encourage their independent exploration.

Finally, different aspects of academic achievement at the end of first grade were related to specific working memory components. Specifically, screening for difficulties in the phonological loop and visuospatial sketchpad in kindergarten can help detect risk for academic difficulties at a young age. Additionally, stimulating these working memory components at an early age, through training and providing a stimulating classroom environment can prevent such issues from arising altogether.

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Table 1

Distribution of Background Characteristics (in Percentages) of the Samples at the End of Kindergarten, the Middle of First Grade and the End of First Grade.

	End of kindergarten	Middle of first grade	p^a	End of first grade	p^b
%	n = 107	n = 51		n = 89	
Boys	47.7	52.8	.289	46.1	.459
Monolingual X speaking	91.4	93.6	.319	92.4	.557
Two-biological-parent-families	84.2	95.7	.003	88.8	.014
At least a Bachelor's degree					
Mother	70.7	84.8	.004	75.6	.025
Father	55.8	64.4	.130	58.7	.212
Above at-risk-for-poverty line	92.0	97.8	.058	94.6	.069
Cumulative risk					
0 risk factors		56.4		43.5	.064
1 risk factor		28.2		30.4	
2 risk factors		12.8		14.5	
3 risk factors		2.6		7.2	
4 risk factors		0.0		1.4	
5 risk factors		0.0		2.9	

[a]p-value based on the chi-square or Fisher's exact test of independence, comparing the sample at the end of kindergarten and the middle of fist grade.

[b]p-value based on the chi-square or Fisher's exact test of independence, comparing the sample at the end of kindergarten and the end of first grade.

Table 2

Mean, standard deviations, repeated measures ANOVA tests and Cohen's d of the working memory outcome measures.

Outcome	WG component	Kindergarten *M* (*SD*)	First grade *M* (*SD*)	*F(1,88)*	*p*	*d*
Digit Recall	PL	19.72 (3.30)	22.82 (3.51)	124.27	<0.001	1.19
Word Recall	PL	22.12 (3.59)	24.15 (3.50)	37.60	<0.001	0.65
Dot Matrix	VSS	15.46 (3.36)	18.34 (3.45)	48.08	<0.001	0.74
Block Recall	VSS	14.65 (3.47)	17.88 (3.61)	50.68	<0.001	0.76
Listening Recall	CE-Verbal	8.26 (2.72)	11.06 (2.87)	69.79	<0.001	0.89
Backwards Digit Recall	CE-Verbal	6.45 (2.42)	9.06 (2.06)	71.70	<0.001	0.91
Odd One Out	CE-Visual	12.79 (3.68)	16.16 (3.52)	60.42	<0.001	0.82
Mister X	CE-Visual	6.85 (2.66)	10.11 (3.64)	61.55	<0.001	0.85

Note. PL = phonological loop, VSS = visuo-spatial sketchpad, CE = central executive

Table 3

Model fit for the working memory models in kindergarten and first grade and comparison of the constraint and unconstraint factor analysis.

Model	χ^2	df	p	CFI	RMSEA	AIC
Kindergarten	18.67	11	.067	.97	.08	66.70
First grade	15.56	11	.158	.96	.06	63.561
Unconstrained	34.26	22	.046	.97	.05	130.26
Constrained	47.32	29	.017	.95	.06	129.32
Difference	13.06	7	.071			

Table 4

Outer loadings of the working memory outcomes and items of the Student-Teacher Relationship Scale.

WM variables	Kindergarten			First grade		
	PL	VSS	CE	PL	VSS	CE
Digit Recall	.840			.840		
Word Recall	.909			.848		
Dot Matrix		.506			.599	
Block Recall		.768			.675	
Listening Recall			.663			.386
Backwards Digit Recall			.689			.366
Odd One Out			.472			.564

Note. WM = working memory, PL = phonological loop, VSS = visuospatial sketchpad, CE = central executive

Table 5

Correlations between all variables included in the models

	Closeness	Conflict	Dependency	Reading 1	Reading 2	Spelling	Mathematics	Cumulative Risk
Kindergarten								
Digit Recall	.07	-.18	-.07	.25*	.33**	.24*	.41**	-.28*
Word Recall	.05	-.21	-.32*	.15	.28**	.13	.39**	-.31**
Dot Matrix	.15	-.08	.02	.32**	.32**	.52***	.31**	-.12
Block Recall	.08	-.03	.11	.22*	.24*	.36**	.30**	-.06
Listening Recall	.27	-.22	-.18	.07	.12	.14	.27**	-.14
Digit Backwards	.19	-.19	-.20	.22*	.33*	.25*	.35*	-.17
Odd One Out	.07	-.16	-.22	.05	.14	.28**	.38**	-.17
First grade								
Digit Recall	-.04	-.10	-.18	.24*	.32**	.11	.33**	-.21
Word Recall	.04	-.10	-.14	.11	.21*	.12	.31**	-.08
Dot Matrix	.07	-.09	-.19	.17	.12	.37**	.37**	-.15
Block Recall	.12	-.05	-.28*	.21*	.26*	.37**	.35**	-.06
Listening Recall	.01	-.15	-.21	.15	.23*	-.04	.15	-.12

Digit Backwards	-.01	.17	-.14	.29**	.33**	.21*	.20	.00
Odd One Out	.20	-.15	-.02	.20	.19	.39**	.34**	.02

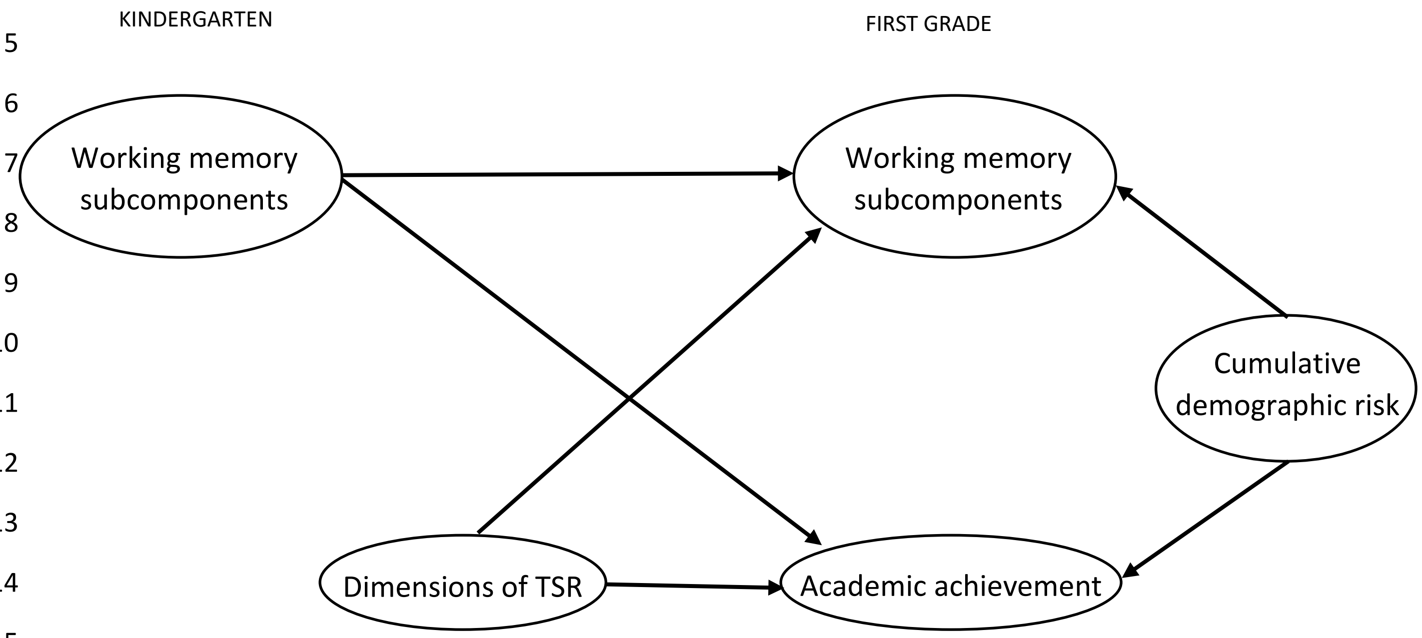

Figure 1. Schematic representation of the full path model tested with Partial Least Square Modelling. TSR = teacher-student relationship